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A STATISTICAL EVALUATION OF THREE METHODS USED IN SAMPLING MEMOMOTION FILM

A THESIS

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SUMMARY

The primary purposes of this research is to determine the differences between non-work activities developed from memomotion film on the one hand, and on the other the non-work activities developed from a concurrent systematic interval study, a systematic sampling of the film, and a random sampling of the film for significance.

The activities of eight workers were filmed for an eight-hour period with a memomotion camera operating at a rate of 25 frames per minute. During the same period, a systematic interval study, using two minute intervals, was made to provide a basis for comparison. Systematic and random sampling of the film provided the other two methods. Replication was provided by the eight workers in the study.

Two approaches were made to analyze the data gathered in this experiment. One technique was that of comparing the variabilities of the methods by using the F test (Snedecor's variance ratio). Corroboration of the results was determined by the use of Cochran's test for homogeneity. The other technique was that of ranking the experimental methods against the control or standard method. The results from this non-parametric technique were corroborated by the use of contingency tables and the Chi Square statistic which tests for the goodness of fit.

Based on the results of the statistical analysis of the data of this research and within the experimental limitations, the general conclusions reached were as follows:

1. The variabilities between the operators were not significant.
2. The sampling methods varied significantly.

3. The systematic sampling of the film duplicated the true percentage distribution of the standard more closely than did the other two methods.
4. The systematic sampling of the film every two minutes adequately defined the non-work occurrences.
5. The random sampling of the film did not compare as well with the true percentage distribution of the standard as did the systematic sampling method.
6. The manual systematic interval study was the least accurate of all the methods under consideration.
7. The quantitative results from the χ^2 test of the contingency tables corroborated the results derived from the ranking technique.

It is recommended that further research be undertaken to ascertain the minimum rate of the systematic sample of the film to adequately define the non-work activities, that an economic balance be sought between the interval rate and cost of film versus the cost of the engineer performing a comparable interval study, and that this study be expanded and repeated so that the results can be tested more rigorously than was possible within the universe of this experiment.

CHAPTER I

INTRODUCTION

Statement of the Problem

The purpose of this thesis is to compare and evaluate statistically the use of memomotion film for analyzing non-work activities with three other sampling methods: a concurrent systematic interval study, a systematic sampling of the film, and a random sampling of the film.

Definition of Allowances

In the establishment of work standards, there are occurrences which interfere with the production of an operator. To identify these occurrences and to determine how much allowance should be made for them is the task of the industrial engineer. Allowances, then, are addition of time to account for these occurrences.

Apple (1) also states that allowances will continue to be a problem in the establishment of work standards as long as we have these interfering occurrences. He further states that the solution of the problem of derived allowances has, in the past, been unscientific and open to question, that allowances are frequently arrived at in a slipshod manner, and that they are even used as a "catch-all" for any errors or difficulties which arise in the determination of the work standard.

Concurring with Apple, Shaw (2) admonishes the engineer to carefully avoid making allowances as "convenient dumping ground." Uhrbrock (3) neatly summed it all up when he stated, ". . . time study, as a 'science' reaches its lowest ebb in the matter of allowances."

The determination (direct measurement) of these allowances is difficult. Since the time of Taylor's inception of time study in 1881, industrial engineers have been concerned with obtaining truly representative allowances to cover these interfering occurrences (4).

The Need for Allowances

The literature is full of examples citing the need for allowances. Good industrial engineering practice demands that any legitimate delay, interruption, or malfunction of equipment be accounted for in the establishment of job standards (5). Taylor (6), in 1883, realized the need for allowances and he obtained them by lengthy time studies. This approach is much the same as in Curley's article in the Taylor Society Bulletin in 1935 (7), except that Curley proposed that continuous time studies be used as a basis for allowances.

In The Handbook of Advanced Time Motion Study (8) Sylvester adds the ratio-delay technique to the above two methods, although it was his opinion that the summarization of past time studies was the most practicable procedure. Nadler and Denholm (9) indicate the ratio-delay technique may produce more accurate results than continuous time studies because the ratio-delay study is applied over a much longer period of time. Their opinions are shared by Petro (10), although for a different reason: the worker is not under pressure due to a stopwatch.

Mundel (11) adds a special motion picture technique called memomotion, along with ratio-delay studies and all-day production studies. One writer appeared to be more concerned with the elimination of the causes for allowances than their determination (12).

On the other hand, a presentation of the need for correct and fair allowances was made by Bellows (13) at the National Motion and Time Study Clinic in 1945. Among the reasons cited by Bellows were these: low allowances are detrimental to employees' morale, and high allowances are actually a gift to the employee and constitute a direct cost to management. He further stated that low allowances caused production to suffer, since they tended to reduce the workers' incentive to produce.

The Determination of Allowances

Judgment

Experience, precedence, tradition, and bargaining are all "judgment" type methods for setting allowances. One might even add the "guesstimate" method under this classification, since all these methods arbitrarily set a percentage addition of time to convert a normalized time into a standard time. Surprisingly enough, these methods are still being used, partly because of the cost that production studies would entail, partly because of emergency, and partly because of a shortage of personnel (14). It is self-evident that the use of these methods is very inexpensive. However, the inaccuracy that is inherent in these methods might cause them to be the most expensive. It is the writer's opinion that these methods were primarily responsible for the statement made by Uhrbrock (3) that ". . . time study, as a 'science' reaches its lowest ebb in the matter of allowances."

Although time studies are thoroughly covered in the literature, the determination of allowances from time studies is generally "glossed over" and other techniques for this determination are referred to. Both Carson and Barnes (15, 16), for example, immediately refer to all day studies (production studies) and delay studies (ratio-delay studies). Curley wrote that, to determine allowances from time studies, the time studies must be completely detailed by taking into account every single work element and delay element, whether the delay element was or was not necessary, and carefully recording it. Sufficient studies would have to be made so that different operators could be checked against each other and all representative delays would be covered. Allowances (excluding fatigue and personal) would then become a matter of record and the need for judgment and experience would be largely eliminated (17).

Production Studies

Other names for production studies are "interruption" or "all-day" studies. Carson stated that, although the study is very simple to take, it is rather tedious because the observer starts at the beginning of the work day and keeps a record of the time for each and every delay that occurs, at the same time recording the productive time separately. This procedure is followed daily, sometimes for weeks, so that all the possible delays and interruptions will be encountered and recorded. Usually, sufficient information can be gathered in the course of ten working days to calculate reasonable allowances. Unfortunately, the length of this study does make it rather expensive, and many companies have neither the money nor the personnel to undertake such a study (18). Another disadvantage of this method is its unpredictable accuracy. Moreover, no theoretical basis for establishing the length of any given study has been developed (19).

Systematic Interval Studies

Studies which are a combination of production studies and ratio-delay studies are called non-random systematic sampling studies. By this method, sample observations are taken at regular intervals (for example, every two minutes) during the course of the study. The observed activity or non-activity is recorded in the same fashion as if it were a ratio-delay study. This method has the advantage of simplicity in planning the observer's work. Also, it facilitates the programming of several different studies to be conducted over the same period, that is, several jobs may be observed during a single observational trip. As good as this method may be, there is a significant disadvantage should there be a regular pattern or a cyclical behavior of the elements or activities being studied. Should these conditions exist, then this method may introduce a significant bias into the estimate (20).

Work Sampling (Ratio-Delay) Studies

Originated by Tippett in 1927 to improve upon subjective procedures used in establishing delay allowances, the ratio-delay method has received widespread recognition since its introduction into the United States by Morrow (21). In brief, this method involves the taking of instantaneous observations, the conversion of these observations into ratios of the day's work, and hence, into developed percentages of time spent for each class of elements or activities that was under observation.

The accuracy of an estimate obtained from this method is dependent on the control and execution of the study procedure, whereas precision is controlled by the number of observations taken (22).

In 1952, Waddell, Editor of Factory Management and Maintenance, changed the name of this method to "work sampling" to stimulate interest in the broader aspects of this technique (23). Barnes (24), at the 12th Annual Management Engineering Conference in 1957, summed the aspects of work sampling into two main uses: (1) work sampling may be used for measuring activity and delays, and (2) under certain circumstances, it may be used to measure manual tasks, that is, to establish a time standard for an operation.

Many concerns such as Eastman Kodak Company, Johns-Manville, Atlantic Refining Company, and others have demonstrated the value of measuring work by this method. The industrial engineers of Johns-Manville, upon the completion of their first application, reported as follows (25): "The use of work sampling for wave incentive applications is almost wholly without limit . . ."

Motion Picture Studies

Classes of Motion Pictures.--The method of motion pictures studies represents the most detailed and accurate procedure for gathering information. When a synchronous motor drives the camera, time values for individual motions, elements, or cycles may be determined by converting frame counts in time in terms of the speed of the camera (26).

The use of the motion-picture camera can be divided into two main classes: (1) those applications where the camera speed is normal (16 frames per second) or faster than normal, and (2) those applications in which the camera speed is slower than normal (time-lapse applications). The usual applications for normal camera speeds or faster tha normal camera speeds are in the field of motion study, micromotion study, and motion study research. For slower than normal speeds, the applications are in the fields of long operation cycles, irregular cycles, crew activities, and studies of long duration. These slower than normal speed techniques are referred to as time-lapse studies or memomotion studies (27).

Normal speed is 16 frames per second or 960 frames per minute. However, for industrial engineering techniques, this speed is increased to 1000 frames per minute, thereby making each frame equivalent to 0.001 minute. Film taken with slower than normal speeds is usually made at speeds of 50, 60, or 100 frames per minute. This does not, however, preclude the possibilities of taking film at even much slower speeds, such as 10 frames per minute or even one frame per minute. For special applications even slower speeds than these are occasionally used, such as one frame every 10 minutes (28).

Motion pictures present many advantages and, in some cases, are the only way of obtaining a good analysis. Work which requires large crews is almost impossible to analyze otherwise. Some of the advantages of motion pictures are as follows (29):

1. Permits greater detailing than eye observation.
2. Permits the analysis of details away from the work area.
3. Provides greater convenience for study.
4. Provides greater accuracy of times.
5. Provides better training aids.
6. Provides a positive record.
7. Provides an excellent means of evaluating methods changes through the use of "before and "after" films.
8. Provides an accurate portrayal of simultaneity.

There are two special phases of studies taken by motion pictures: *micromotion studies and memomotion studies. Although both techniques* were originated by the Gilbreths, the term "memomotion" study, for this form of micromotion study, was suggested by Mundel (30).

Micromotion Studies.--Briefly, micromotion study involves taking motion pictures with a timing device in the picture or with a motion picture camera operating at a constant and known speed for the purpose of job analysis. It is also used:

1. As an aid in studying the activities of two or more persons on group work.
2. As an aid in studying the relationship of the activities of the operator and the machine.
3. As a means of timing operations.
4. As an aid in obtaining motion-time data for synthetic time standards.
5. As a permanent record of the method and time of activities of the operator and the machine.
6. For research in the field of motion and time study.

However, its main use is to assist in finding the most efficient method of doing work. When an operation for micromotion study is filmed, the camera speed is normal unless the operation involves very fast and/or complex hand motions. Then speeds faster than normal are used to provide greater coverage. Due to the speeds used in taking micromotion film, large amounts of film are exposed in relatively short periods of time, and unless allowances are to be determined within cycles of short, highly complex hand motions, allowances are almost never determined from micromotion studies (31).

Memomotion Studies.--Memomotion studies were developed to analyze long work cycles and to analyze work which requires several people to work together (32). Other uses for memomotion are the studies of irregular cycles and the recording of picture histories of methods and working conditions. Memomotion has in addition to most of the advantages of micromotion two important advantages: greatly reduced film costs, and film analysis time. When projected at normal speeds, hours of filmed activity can be reduced to minutes of viewing time, so that one receives a rapid view of the effectiveness of layout, machines, manpower, or material usage, and an exaggeration of the actual losses.

In the analysis of a memomotion film, the film is first reviewed to obtain the concept of suitable elements. Then, by the use of a projector with a frame counter and a special worksheet (a breakdown sheet for each element), the activities of each operator are analyzed frame by frame. A frame count is maintained on each element per operator. After the first operator is analyzed, the procedure is repeated on the second operator until each has been analyzed. The data is then summarized as desired (33).

In the matter of allowances, the elemental breakdown sheet will contain each type of delay that is under consideration. A summation of occurrences of each type of delay multiplied by the equivalent time value of each frame, the product of which is then divided by the total time spent in the filmed activity, will result in, when multiplied by 100, the percentage of occurrence for each type of delay in that activity. In formula form, this is

$$\% \; D = \frac{(\Sigma A)\,(B)}{C} \times 100 \,, \tag{34}$$

where ΣA = the sum of the number of frames in which the delay under consideration occurs,

B = the equivalent time per frame,

C = the total number of frames of the filmed study, and

D = the delay element under consideration.

Experimental Procedures

In 1950 Dwyer worked on a technique with Lehrer that pointed out the usefulness of a motion picture camera, activated for short runs at regular intervals, for the collection of certain types of data. This work led to further exploration by Pickett (35) as outlined below.

Instead of using regular intervals, Pickett incorporated the ratio-delay technique by taking single frame exposures at random intervals while taking a simultaneous, visual ratio-delay study for comparison. Although his results were negative since the two studies did not satisfactorily agree, his work led to the findings by Tolbert (36) later on.

Tolbert was of the opinion that a single frame exposure did not provide enough information regarding the actual study of the operation in question. Using a concurrent all-day production study for comparison, the results of Tolbert (37), subject to the limitations of his study, demonstrated the feasibility of using a photographic ratio-delay technique when several frames were exposed at random intervals.

A review of these experimental methods, together with previous experience in the use of memomotion studies and systematic interval studies, led this writer into the investigation of determining whether allowances set by various types of sampling methods would agree with those determined from a memomotion film.

CHAPTER II

PROCEDURE

Description of Procedure

Introduction.--In the conversion of normalized time values into standard time values, allowances must be added for personal needs, fatigue, and delays. It is very difficult to determine accurately the direct measurement of these allowances. In many cases an allowance is the result of company policy, or judgement based on long experience, or precedence, or even tradition. In some cases certain allowances may appear in union contracts, and in still other cases, the individual time study engineer may resort to his own judgment in setting the amount.

For a particular operation, the time consumed in a work day in various non-productive activities can be estimated by special studies employing interruption studies, work sampling studies, systematic interval studies, and motion picture studies.

All of these methods are either very expensive or time-consuming. Both the interruption study and the systematic interval study (better known as non-random systematic sampling at regular intervals) require the presence of an engineer throughout the course of the study. Work sampling studies, when conducted over a protracted period of time, do not require the constant presence of an engineer, only during those times when the engineer must take his readings. Motion pictures are expensive, yet their cost can be considerably decreased through the application of a special technique known as memomotion.

To determine the required allowances, one must use one or more of these techniques, unless the amounts of these allowances have been set by one or more of the previously mentioned systems.

Thus the basic problem is how these allowances can be determined accurately and inexpensively.

Since the first three methods essentially require the constant presence of an engineer, the solution apparently lies with the use of motion pictures. Therefore, the following study was designed to test the use of motion pictures, using memomotion techniques with appropriate adaptations from the systematic interval type of study and the work sampling type of study.

Memomotion Study.--A memomotion camera having a speed of 25 frames per minute was used to record the activities of eight men fabricating a series of small assemblies during a normal eight-hour period. This film was used as a control to determine the various non-productive activities that occurred during this eight-hour period. Two systematic interval studies, conducted by two engineers, were to be taken concurrently with the film on each of the eight men under observation. An unfortunate incident occurred during the evening prior to the filming which precluded the taking of one of the systematic interval studies. A replacement for this engineer was unobtainable on such short notice, and the postponement of this filming was impossible. As a result, only one systematic interval study was taken.

Systematic Interval Study.--The Lockheed Aircraft Corporation, Marietta, Georgia, uses a systematic interval study for the determination of time standards of long cycle operations, crew activity, irregular cycles, and for allowances. The method consists of recording (and rating when used for time standards) the activities of several operators at two-minute intervals. Having been known as production delay studies and multi-minute studies, they are now called time delay studies. The activities that are recorded in these time delay studies are coded. For this thesis, such a study was conducted during the filming to compare the results of these two studies.

The coding for the various work and non-work elements is listed below. The elemental breakdown for "work" activities is not included for these findings, since this thesis is concerned solely with the non-work elements.

Work Elements:

	Therblig	Code
Assemble	(A)	A
Bolt	(A)	B
Complete (aside completed part) .	(RL & RL)	C
Clean-up	(A)	CU
Drill and burr	(A)	D
Load and unload jig	(A)	LJ
Obtain parts or blueprints . . .	(A)	OP
Sort and unwrap parts	(A)	P
Rivet	(A)	R
Set-up	(A)	SU
Tool, get and return	(A)	T
Wire, safety wire parts	(A)	W

Non-Work Elements:

Crowding	(AD)	CR

This element occurs when an operator is forced to stop working due to interference by another worker.

Non-Work Elements (Continued):

	Therbligs	Code
First Aid . . . . This element occurs when an operator is injured and has to leave the work area to obtain treatment.	(UD)	FA
Idle . . . . This element occurs when an operator is waiting for help from another worker who is not yet ready with his part in the work.	(AD)	I
Indirect Labor . . . . This element occurs when an operator is contacted by supervision and is stopped in the performance of his work.	(UD)	IL
Looking for Equipment or Tools . This element occurs when an operator is looking for jigs, tools, and other equipment.	(S)	LE
Looking for Parts . . . . This element occurs when an operator is searching for MSP (manufactured small parts) in the MSP bins, for parts he had placed on his work bench, or in his tool box.	(S)	LP
Lost Time . . . . This element occurs when an operator stops work: to walk or talk, make motions to simulate work, or completely for no reason at all.	(AD)	LT
Personal Time . . . . This element occurs when an operator stops work to satisfy personal needs.	(AD)	PT

Non-Work Elements (Continued)

	Therbligs	Code
Study Prints . . . . This element occurs when an operator stops work to study a blueprint after the set-up element includes sufficient time for the worker to get familiar with the prints.	(Pn)	SP
Union Activities . . . . This element occurs when, as a union representative, the operator stops to discuss union matters with other workers, to investigate activities that have union connotations. This code is assigned to the union representative only.	(AD)	U

A time standards engineer, along with the writer filling in for relief, conducted the systematic interval study on eight operators in the morning and on six operators in the afternoon, using the above symbols for the work and non-work elements. The interval used for this study was two minutes.

Systematic Sampling of the Film.--Using a frame counter, two systematic sampling studies were developed from the film:

1. M_1, a systematic sample using every 50th frame starting with Frame No. 50.
2. M_2, a systematic sample using every 50th frame starting with Frame No. 25.

The reasons for selecting these two methods are as follows: The systematic interval study was made at two-minute intervals. The memo-motion film was taken at 25 frames per minute. Therefore, every 50th frame on the film was the equivalent to the two-minute interval of the systematic interval study. Thus the film frame and the systematic interval study coincided and a direct comparison was possible between the two methods. Furthermore, the manual method was started on the even minute interval (7:00, 7:02, 7:04 . . .), and Frame No. 50 was also taken at 7:02. The second systematic sample, M_2, was deliberately chosen to fall exactly between the frames chosen in the first sample to eliminate any possible dependency that two or more frames might have, should these frames be successive. In addition, since these frames of both samples are at constant intervals, the addition of all the frames of the first method and of the second method will provide for a third sample, M_3, consisting of a systematic frame sample of every 25th frame.

Should this method prove to be economical as well as accurate for determining the necessary allowances from non-productive work elements, then a memomotion film, taken at this rate of one frame per every two minutes, could be substituted for those films which are taken at higher rates of speed with a considerable saving of film.

Random Sampling of the Film.--Using a frame counter, two random sampling studies were developed from the film:

1. M_4, a random sample of 500 frames.
2. M_5, another random sample of 500 frames.

Before the sample size can be determined, an estimate of the percentage occurrence of the non-work activities must be made. Since the film was taken at the Lockheed Aircraft Corporation, Marietta, Georgia on Lockheed employees, a value of 10 per cent was arbitrarily selected as being representative of the value that is used by Lockheed. With this value, the sample size can be determined from the following formula:

$$Sp = 2\sqrt{\frac{p(1-p)}{N}}\ , \qquad (38)$$

where S = desired relative accuracy,

p = percentage occurrence of the non-work activity, being measured, expressed as a decimal, that is, 10% = 0.10,

N = total number of random readings (sample size).

Using a confidence level of 95 per cent and an accuracy of plus or minus 10 per cent, the required number of readings (N) from the above formula is 3600.

Since eight workers were under observation, each frame will yield eight readings. Therefore, 3600 readings divided by eight observations per reading yields 450 observations. To facilitate computations and to provide a margin for error, instead of 450 observations, 500 were taken.

For comparisons, the two samples, M_4 and M_5, were combined and coded as M_6.

The Operations

Worker Identification.--Eight employees were covered by the film and the systematic interval study. As an aid for future explorations of the film, each worker was identified by his appearance and manner of dress. They are as follows:

Worker A - Located at Table No. 1, this worker is wearing a plaid, short-sleeved shirt over very dark trousers. He is teamed with Worker B.

Worker B - Located at Table No. 1, this worker is wearing a white, vertically striped short-sleeved sport shirt tucked into very light trousers. He is teamed with Worker A.

Worker C - Located at Table No. 2, this worker is wearing a black, short-sleeved sport shirt tucked into light colored trousers. He is working along but is aided on occasion by Worker H.

Worker D - Located at Table No. 3, this worker is dressed in very light clothes covered by a knee-length, bib-front, black apron. He is teamed with Worker E.

Worker E - Located at Table No. 3, this worker is wearing a black, short-sleeved sport shirt tucked into very dark trousers. He is teamed with Worker D.

Worker F - Located at Table No. 4, this worker is wearing a Navy-type, white "tee" shirt and dark trousers covered by a short white apron that reaches halfway to his knees. He is teamed with Worker G.

Worker G - Located at Table No. 4, this worker is wearing a white, short-sleeved sport shirt tucked into very light trousers. He is teamed with Worker F.

Worker H - Located at Table No. 5, this worker is wearing a Navy-type, white "tee" shirt tucked into light trousers. There is a drill press mounted on this table. He is working alone, but assists Worker C on occasion.

The three other employees found in most of the frames are the three time study engineers who assisted the writer in the data collection for this thesis. They are identified as "X", "Y", and "Z" in the accompanying photograph (Figure 1) as well as the eight workers above.

The Workplace Layout.--The work benches were laid out in lines, back to back. For this study, two lines of two benches each were taken as well as a fifth bench in a third line. Figure 1 illustrates this pattern.

The Camera and Set-up.--The camera used was a Keystone Criterion, 16mm, Model A-9, Georgia Tech No. 17, which had been modified by a synchronous motor to take memomotion pictures at the rate of 25 frames per minute. The exposure rate was 1/30 second and the lens was rated at f3.5. Since the brightness measured 5 in Weston units, an Eastman Tri-X negative film was chosen. Positive prints were made from the developed negative. The camera was mounted on a tripod, the tripod having been elevated by a hydraulic lift stand to a height of approximately nine feet above the

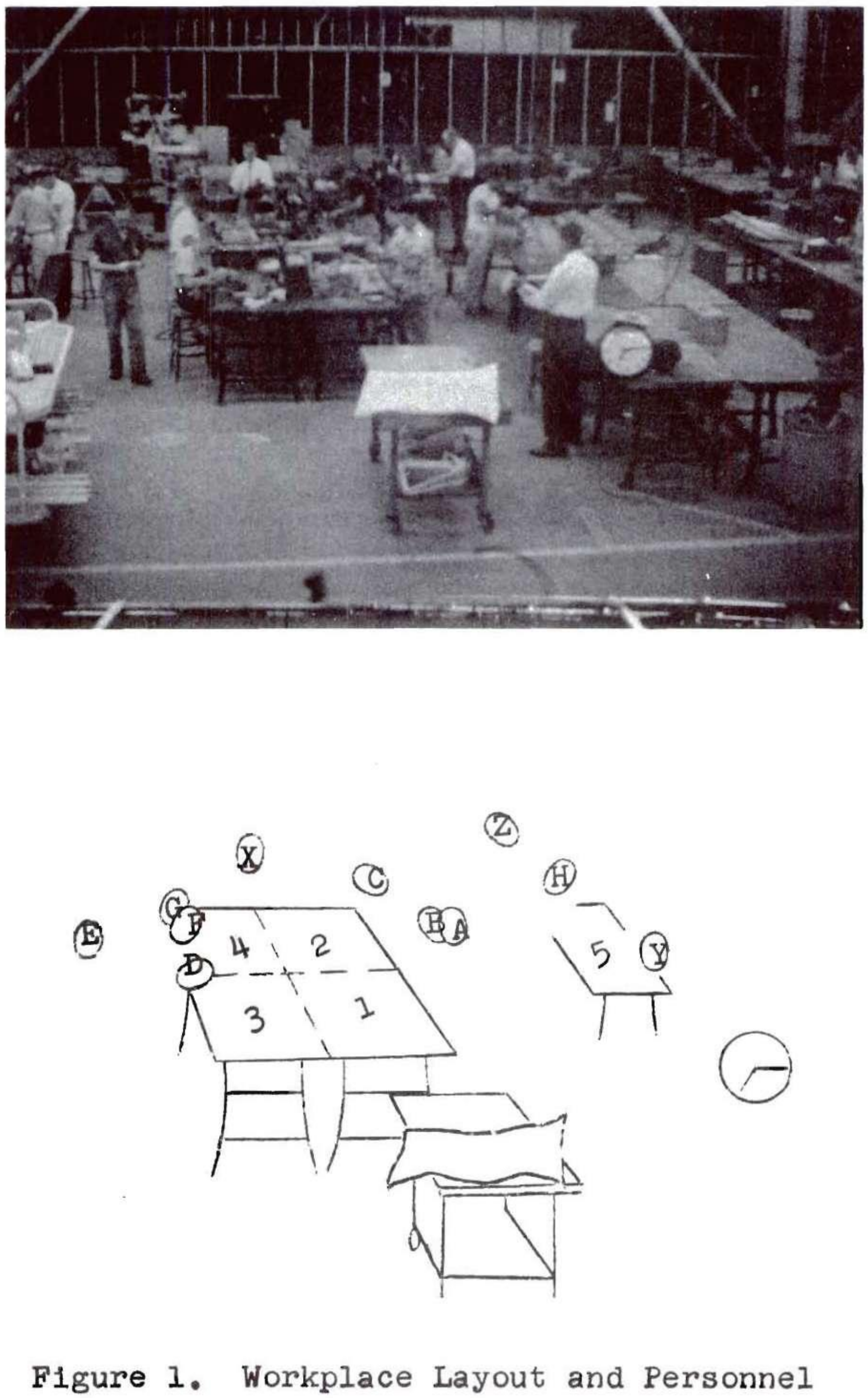


Figure 1. Workplace Layout and Personnel

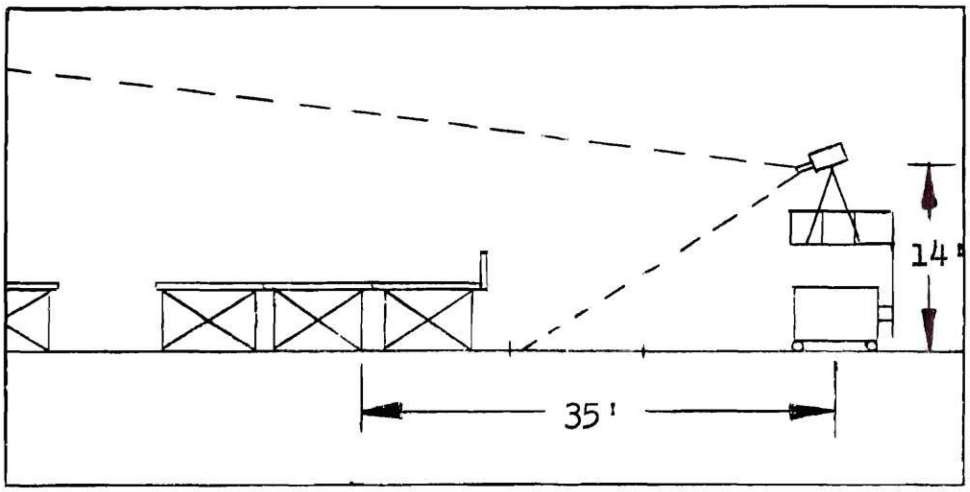
floor level, thereby placing the camera at an elevation of some 14 feet above the floor level. In accordance with the built-in range finder in the camera, the hydraulic lift was moved away from the work benches until all five benches were properly framed. Figure 2 illustrates the camera layout from two viewpoints, plan and elevation.

Filming the Operations.--The total working period covered by film started at 7:00 A.M. and terminated at 3:45 P.M. of the same day. During the course of the day, there were two break periods: 9:30 A.M. to 9:40 A.M., and 2:00 P.M. to 2:10 P.M., as well as a lunch period from 11:30 A.M. to 12:15 P.M. The break periods and the lunch period separated the day into four clearly identified working periods.

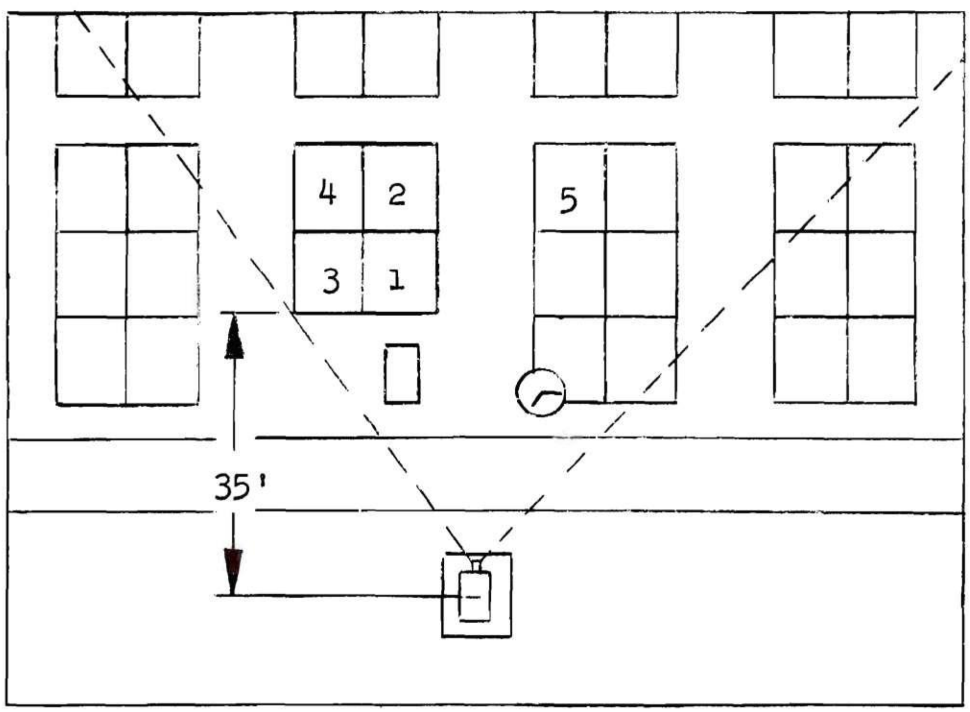
The capacity of the camera was 100 feet of film. At forty 16 mm frames per foot, 100 feet of film is equivalent to 4000 frames. Of the four working periods, the longest period was 2-1/2 hours or 150 minutes. By dividing the 400 frames by this time in minutes, the resulting quotient would give the required number of frames per minute that could be employed in a memomotion film to avoid reloading the camera during the filming of a working period. Since this quotient was 26-2/3 frames per minute, a memomotion camera capable of taking pictures at the rate of 25 frames per minute would suffice.

For technical reasons the two break periods had to be lengthened by nine and seven minutes respectively. Therefore, the four identified work periods were as follows:

1st period -	7:00 - 9:30 A.M.:	total time - 150 minutes
2nd period -	9:49 - 11:30 A.M.:	total time - 101 minutes
3rd period -	12:15 - 2:00 P.M.:	total time - 105 minutes
4th period -	2:17 - 3:43 P.M.:	total time - 86 minutes
	Grand Total	- 442 minutes



Elevation



Plan

Figure 2. Camera Layout: Elevation and Plan

The first period was filmed in its entirety, and at 9:30 A.M., when the whistle blew, a lens cap was placed over the lens to run the leader. After the leader was made, the camera was reloaded and the second period was filmed until the lunch period when the same procedure for filming the leader was followed.

The two afternoon working periods were filmed in a similar fashion. Figure 3 is a reproduction of a section of this film.

Figure 3. Sample of Memomotion Film

CHAPTER III

THE ANALYSIS

The Systematic Interval Study Analysis

The systematic interval study was analyzed and developed, according to the procedure as outlined in Chapters I and II, into the number of occurrences of each work element and non-work element as listed in Chapter II. These occurrences per each element are listed in Table 1 through Table 8 for each operator and are summed in Table 9 for all operators. These summations are coded as C_2.

The Film Analysis

The film analysis was made with a Bell and Howell Time and Motion Study projector, Model XD, Design No. 57, equipped with a frame counter and heat filter. From the large IBM clock which was placed in the picture and with the use of a 50x magnifier lens, the beginning and end of the four working periods were identified and recorded in terms of frame numbers. These four periods are (in frame numbers):

1st period - Frame 00001-03752:	total -	3752 frames
2nd period - Frame 03792-06321:	total -	2530 frames
3rd period - Frame 06616-09248:	total -	2632 frames
4th period - Frame 09287-11448:	total -	2161 frames
	Grand Total -	11075 frames

From Chapter II, the total work time was determined to be 442 minutes. Since the film was taken at a speed of 25 frames per minute, each frame is then equivalent to 1/25 minute or 0.04 minutes. Using the grand total of 11075 frames, the equivalent time value becomes

Table 1. Summary of Results, Worker A

ELEMENTS		METHODS											
		C_1		C_2		M_1		M_2		M_4		M_5	
		f	%	f	%	f	%	f	%	f	%	f	%
	A	3733	33.71	72	32.58	75	33.94	72	32.58	166	33.20	156	31.20
	B	-	-	-	-	-	-	-	-	-	-	-	-
	C	483	4.36	10	4.52	12	5.43	10	4.52	20	4.00	24	4.80
	CU	297	2.68	9	4.07	7	3.17	5	2.26	13	2.60	18	3.60
W	D	1529	13.81	32	14.48	33	14.93	30	13.57	72	14.40	56	11.20
O	LJ	1766	15.95	26	11.76	33	14.93	38	17.19	56	11.20	97	19.40
R	OP	86	.78	7	3.17	-	-	2	.90	4	.80	5	1.00
K	P	1265	11.42	22	9.95	24	10.86	26	11.76	63	12.60	52	10.40
	R	-	-	-	-	-	-	-	-	-	-	-	-
	SU	447	4.04	6	2.71	9	4.07	10	4.59	18	3.60	20	4.00
	T	117	1.06	1	.45	3	1.36	-	-	8	1.60	5	1.00
	W	-	-	-	-	-	-	-	-	-	-	-	-
TOTALS		9723	87.79	185	83.71	196	88.69	193	87.33	420	84.00	433	86.60
	CR	-	-	-	-	-	-	-	-	-	-	-	-
N	FA	-	-	-	-	-	-	-	-	-	-	-	-
O	I	185	1.67	4	1.81	3	1.36	4	1.81	7	1.40	8	1.60
N	IL	75	.68	3	1.36	2	.90	1	.45	6	1.20	5	1.00
-	LE	46	.42	2	.90	1	.45	1	.45	4	.80	3	.60
W	LP	221	2.00	8	3.62	5	2.26	4	1.81	9	1.80	15	3.00
O	LT	76	.69	6	2.71	1	.45	2	.90	5	1.00	6	1.20
R	PT	713	6.44	8	3.62	13	5.88	15	6.79	48	9.60	28	5.60
K	SP	36	.33	5	2.26	-	-	1	.45	1	.20	2	.40
	U	-	-	-	-	-	-	-	-	-	-	-	-
TOTALS		1352	12.21	36	16.29	25	11.31	28	12.67	80	16.00	67	13.40
GRAND TOTALS		11075	100.0	221	100.0	221	100.0	221	100.0	500	100.0	500	100.0

Table 2. Summary of Results, Worker B

ELEMENTS		METHODS											
		C_1		C_2		M_1		M_2		M_4		M_5	
		f	%	f	%	f	%	f	%	f	%	f	%
	A	3638	32.85	72	32.59	72	32.59	71	32.13	158	31.60	177	35.40
	B	-	-	-	-	-	-	-	-	-	-	-	-
	C	641	5.79	1	.45	9	4.07	16	7.24	27	5.40	17	3.40
	CU	222	2.00	4	1.81	6	2.71	5	2.26	10	2.00	8	1.60
W	D	1739	15.70	36	16.29	34	15.38	38	17.19	81	16.20	77	15.40
O	LJ	3067	27.69	45	20.36	62	28.05	59	26.70	139	27.80	135	27.00
R	OP	190	1.72	-	-	5	2.26	4	1.81	7	1.40	10	2.00
K	P	37	.33	12	5.43	-	-	1	.45	4	.80	2	.40
	R	-	-	-	-	-	-	-	-	-	-	-	-
	SU	17	.15	7	3.17	1	.45	-	-	1	.20	-	-
	T	47	.42	2	.90	1	.45	1	.45	1	.20	1	.20
	W	-	-	-	-	-	-	-	-	-	-	-	-
TOTALS		9598	86.66	179	81.00	190	85.97	195	88.24	428	85.60	427	85.40
	CR	-	-	-	-	-	-	-	-	-	-	-	-
N	FA	-	-	-	-	-	-	-	-	-	-	-	-
O	I	363	3.28	12	5.43	9	4.07	4	1.81	11	2.20	18	3.60
N	IL	148	1.34	6	2.71	3	1.36	2	.90	5	1.00	8	1.60
-	LE	5	.05	1	.45	-	-	-	-	2	.40	-	-
W	LP	-	-	-	-	-	-	-	-	-	-	-	-
O	LT	286	2.58	7	3.17	5	2.26	7	3.17	15	3.00	12	2.40
R	PT	675	6.09	16	7.24	14	6.33	13	5.88	39	7.80	35	7.00
K	SP	-	-	-	-	-	-	-	-	-	-	-	-
	U	-	-	-	-	-	-	-	-	-	-	-	-
TOTALS		1477	13.34	42	19.00	31	14.03	26	11.76	72	14.40	73	14.60
GRAND TOTALS		11075	100.0	221	100.0	221	100.0	221	100.0	500	100.0	500	100.0

Table 3. Summary of Results, Worker C

	ELEMENTS	METHODS											
		C_1		C_2		M_1		M_2		M_4		M_5	
		f	%	f	%	f	%	f	%	f	%	f	%
	A	2713	43.19	13	10.32	54	42.86	57	45.60	112	38.23	127	44.88
	B	-	-	-	-	-	-	-	-	-	-	-	-
	C	-	-	-	-	-	-	-	-	-	-	-	-
	CU	-	-	-	-	-	-	-	-	-	-	-	-
W	D	890	14.17	33	26.19	18	14.29	18	14.40	39	13.31	24	8.48
O	LT	1287	20.49	42	33.33	29	23.02	25	20.00	69	23.55	66	23.32
R	OP	48	.76	-	-	-	-	1	.80	-	-	3	1.06
K	P	69	1.10	1	.79	1	.79	2	1.60	3	1.02	7	2.47
	R	556	8.85	17	13.49	11	8.73	11	8.80	30	10.24	27	9.54
	SU	109	1.74	3	2.38	3	2.38	2	1.60	5	1.71	6	2.12
	T	35	.56	1	.79	-	-	1	.80	1	.34	1	.35
	W	-	-	-	-	-	-	-	-	-	-	-	-
TOTALS		5707	90.85	110	87.30	116	92.06	117	93.60	259	88.40	261	92.23
	CR	-	-	-	-	-	-	-	-	-	-	-	-
N	FA	-	-	-	-	-	-	-	-	-	-	-	-
O	I	50	.80	3	2.38	2	1.59	-	-	5	1.71	3	1.06
N	IT	157	2.50	2	1.59	2	1.59	3	2.40	6	2.05	9	3.18
-	LE	-	-	-	-	-	-	-	-	-	-	-	-
W	LP	-	-	1	.79	-	-	-	-	-	-	-	-
O	LT	203	3.23	3	2.39	3	2.38	-	-	10	3.41	5	1.77
R	PT	139	2.21	7	5.55	2	1.59	5	4.00	11	3.75	5	1.77
K	SP	26	.41	-	-	1	.79	-	-	2	.68	-	-
	U	-	-	-	-	-	-	-	-	-	-	-	-
TOTALS		575	9.15	16	12.70	10	7.94	8	6.40	34	11.60	22	7.77
GRAND TOTALS		6282	100.0	126	100.0	126	100.0	125	100.0	293	100.0	283	100.0

Table 4. Summary of Results, Worker D

ELEMENTS		METHODS											
		C_1		C_2		M_1		M_2		M_4		M_5	
		f	%	f	%	f	%	f	%	f	%	f	%
	A	749	6.76	16	7.24	12	5.43	11	4.98	13	2.60	43	8.60
	B	3760	33.95	63	28.51	77	34.84	75	33.94	201	40.20	159	31.80
	C	-	-	-	-	-	-	-	-	-	-	-	-
	CU	-	-	-	-	-	-	-	-	-	-	-	-
W	D	268	2.42	3	1.36	5	2.26	6	2.71	3	.60	9	1.80
O	LJ	644	5.81	17	7.69	13	5.88	12	5.43	19	3.80	36	7.20
R	OP	342	3.09	13	5.88	7	3.17	6	2.71	12	2.40	13	2.60
K	P	95	.86	-	-	2	.90	2	.90	5	1.00	4	.80
	R	259	2.34	5	2.26	5	2.26	6	2.71	14	2.80	8	1.60
	SU	46	.42	-	-	1	.45	1	.45	3	.60	6	1.20
	T	563	5.08	14	6.33	12	5.43	13	5.88	21	4.20	27	5.40
	W	-	-	-	-	-	-	-	-	-	-	-	-
TOTALS		6726	60.73	131	59.28	134	60.63	132	59.73	291	58.20	305	61.00
	CR	-	-	-	-	-	-	-	-	-	-	-	-
N	FA	-	-	-	-	-	-	-	-	-	-	-	-
O	I	620	5.60	32	14.48	12	5.43	13	5.88	35	7.00	26	5.20
N	IL	255	2.30	2	.90	5	2.26	5	2.26	8	1.60	15	3.00
-	LE	-	-	1	.45	-	-	-	-	-	-	-	-
W	LP	-	-	-	-	-	-	-	-	-	-	-	-
O	LT	2258	20.39	42	19.00	44	19.91	47	21.27	100	20.00	105	21.00
R	PT	820	7.40	8	3.61	18	8.14	16	7.24	48	9.60	29	5.80
K	SP	396	3.58	5	2.26	8	3.62	8	3.62	18	3.60	20	4.00
	U	-	-	-	-	-	-	-	-	-	-	-	-
TOTALS		4349	39.27	90	40.72	87	39.37	89	40.27	209	41.80	195	39.00
GRAND TOTALS		11075	100.0	221	100.0	221	100.0	221	100.0	500	100.0	500	100.0

Table 5. Summary of Results, Worker E

ELEMENTS		METHODS											
		C_1		C_2		M_1		M_2		M_4		M_5	
		f	%	f	%	f	%	f	%	f	%	f	%
	A	5485	49.53	102	46.15	112	50.68	115	52.04	268	53.60	243	48.60
	B	-	-	-	-	-	-	-	-	-	-	-	-
	C	44	.40	-	-	1	.45	-	-	3	.60	-	-
	CJ	69	.62	-	-	1	.45	1	.45	6	1.20	-	-
W	D	832	7.51	20	9.05	16	7.24	18	8.14	33	6.60	44	8.80
O	LJ	427	3.86	3	1.36	7	3.17	9	4.07	16	3.20	21	4.20
R	OP	314	2.84	5	2.26	6	2.71	7	3.17	14	2.80	13	2.60
K	P	233	2.10	4	1.81	5	2.24	4	1.81	14	2.80	16	3.20
	R	735	6.64	17	7.69	14	6.33	13	5.88	13	2.60	32	6.40
	SU	180	1.63	1	.45	3	1.36	3	1.86	9	1.80	8	1.60
	T	700	6.32	6	2.71	15	6.79	13	5.88	34	6.80	21	4.20
	W	-	-	-	-	-	-	-	-	-	-	-	-
TOTALS		9019	81.44	158	71.49	180	81.45	183	82.81	410	82.00	298	79.60
	CR	28	.25	1	.45	1	.45	1	.45	1	.20	1	.20
N	FA	-	-	-	-	-	-	-	-	-	-	-	-
O	I	421	3.80	18	8.14	8	3.62	[illegible]	2.24	20	4.00	24	4.80
N	IL	377	3.40	5	2.26	9	4.07	8	3.62	15	3.00	22	4.40
-	LE	5	.05	-	-	-	-	-	-	1	.20	-	-
W	LP	-	-	-	-	-	-	-	-	-	-	-	-
O	LT	408	3.68	17	7.69	8	3.62	7	3.17	14	2.80	18	3.60
R	PT	461	4.16	14	6.33	8	3.62	9	4.07	27	5.40	25	5.00
K	SP	356	3.21	8	3.62	7	3.17	8	3.62	12	2.40	12	2.40
	U	-	-	-	-	-	-	-	-	-	-	-	-
TOTALS		2056	18.56	63	28.51	41	18.55	38	17.19	90	18.00	102	20.40
GRAND TOTALS		11075	100.0	221	100.0	221	100.0	221	100.0	500	100.0	500	100.0

Table 6. Summary of Results, Worker F

	ELEMENTS	METHODS											
		C_1		C_2		M_1		M_2		M_4		M_5	
		f	%	f	%	f	%	f	%	f	%	f	%
	A	6071	54.82	130	58.82	124	56.11	128	57.92	277	55.40	276	55.20
	B	740	6.68	15	6.79	15	6.79	14	6.33	38	7.60	28	5.60
	C	55	.50	1	.45	1	.45	1	.45	3	.60	1	.20
	CU	47	.42	-	-	1	.45	1	.45	5	1.00	4	.80
W	D	-	-	1	.45	-	-	-	-	-	-	-	-
O	LJ	108	.98	-	-	2	.90	3	1.36	4	.80	11	2.20
R	OP	565	5.10	3	1.36	8	3.62	10	4.59	18	3.60	15	3.00
K	P	156	1.41	1	.45	4	1.81	2	.90	6	1.20	16	3.20
	R	-	-	-	-	-	-	-	-	-	-	-	-
	SU	489	4.42	4	1.81	9	4.07	10	4.59	23	4.60	23	4.60
	T	196	1.77	9	4.07	2	.90	4	1.81	12	2.40	8	1.60
	W	-	-	-	-	-	-	-	-	-	-	-	-
TOTALS		8427	76.09	164	74.21	166	75.11	173	78.28	386	77.20	382	76.40
	GR	24	.22	1	.45	1	.45	-	-	1	.20	1	.20
N	FA	527	4.76	18	8.14	11	4.98	10	4.59	22	4.40	14	2.80
O	I	346	3.12	8	3.62	10	4.59	6	2.71	22	4.40	14	2.80
N	IL	222	2.00	3	1.36	5	2.26	4	1.81	4	.80	17	3.40
-	LE	-	-	1	.45	-	-	-	-	-	-	-	-
W	LP	-	-	-	-	-	-	-	-	-	-	-	-
O	LT	49	.44	3	1.36	-	-	1	.45	3	.60	4	.80
R	PT	1072	9.68	15	6.79	23	10.41	17	7.69	50	10.00	52	10.40
K	SP	408	3.68	8	3.62	5	2.26	10	4.59	12	2.40	16	3.20
	U	-	-	-	-	-	-	-	-	-	-	-	-
TOTALS		2648	23.91	57	25.79	55	24.89	48	21.72	114	22.80	118	23.60
GRAND TOTALS		11075	100.0	221	100.0	221	100.0	221	100.0	500	100.0	500	100.0

Table 7. Summary of Results, Worker G

ELEMENTS		METHODS											
		C_1		C_2		M_1		M_2		M_4		M_5	
		f	%	f	%	f	%	f	%	f	%	f	%
	A	6955	62.80	132	59.73	139	62.90	143	64.71	287	57.40	321	64.20
	B	899	8.12	17	7.69.	17	7.69	18	8.14	47	9.40	35	7.00
	C	-	-	1	.45	-	-	-	-	-	-	-	-
	CU	92	.83	2	.90	1	.45	3	1.36	3	.60	1	.20
W	D	-	-	-	-	-	-	-	-	-	-	-	-
O	LJ	-	-	-	-	-	-	-	-	-	-	-	-
R	OP	824	7.44	20	9.05	18	8.14	13	5.88	37	7.40	40	8.00
K	P	309	2.79	2	.90	4	1.81	4	1.81	9	1.80	13	2.60
	R	-	-	-	-	-	-	-	-	-	-	-	-
	SU	203	1.83	5	2.26	4	1.81	4	1.81	7	1.40	13	2.60
	T	352	3.18	6	2.71	7	3.17	7	3.17	12	2.40	16	3.20
	W	-	-	-	-	-	-	-	-	-	-	-	-
TOTALS		9634	86.99	185	83.71	190	85.97	192	86.88	402	80.40	439	87.80
	CR	34	.31	1	.45	1	.45	-	-	1	.20	-	-
N	FA	-	-	-	-	-	-	-	-	-	-	-	-
O	I	189	1.71	10	4.52	4	1.81	4	1.81	8	1.60	8	1.60
N	IL	232	2.09	2	.90	6	2.71	4	1.81	11	2.20	9	1.80
-	LE	-	-	-	-	-	-	-	-	-	-	-	-
W	LP	19	.17	-	-	-	-	1	.45	2	.40	-	-
O	LT	73	.66	2	.90	1	.45	-	-	22	4.40	8	1.60
R	PT	687	6.20	16	7.24	14	6.33	17	7.69	46	9.20	29	5.80
K	SP	207	1.87	5	2.26	5	2.26	3	1.36	8	1.60	7	1.40
	U	-	-	-	-	-	-	-	-	-	-	-	-
TOTALS		1441	13.01	36	16.29	31	14.03	29	13.12	98	19.60	61	12.20
GRAND TOTALS		11075	100.0	221	100.0	221	100.0	221	100.0	500	100.0	500	100.0

Table 8. Summary of Results, Worker H

	ELEMENTS	METHODS											
		C_1		C_2		M_1		M_2		M_4		M_5	
		f	%	f	%	f	%	f	%	f	%	f	%
	A	57	.91	-	-	1	.79	1	.80	3	1.02	2	.70
	B	-	-	-	-	-	-	-	-	-	-	-	-
	C	-	-	-	-	-	-	-	-	-	-	-	-
	CU	-	-	-	-	-	-	-	-	-	-	-	-
W	D	-	-	-	-	-	-	-	-	-	-	-	-
O	LJ	-	-	-	-	-	-	-	-	-	-	-	-
R	OP	57	.91	-	-	2	1.59	-	-	5	1.71	3	1.06
K	P	-	-	-	-	-	-	-	-	-	-	-	-
	R	529	8.42	9	7.15	11	8.73	10	8.00	30	10.24	36	12.72
	SU	31	.49	1	.79	-	-	1	.80	-	-	2	.70
	T	204	3.25	10	7.94	4	3.17	4	3.20	7	2.39	3	1.06
	W	3993	63.56	89	70.63	80	63.49	82	65.60	181	61.77	181	63.96
TOTALS		4871	77.54	109	86.51	98	77.78	98	78.40	226	77.13	227	80.21
	CR	-	-	-	-	-	-	-	-	-	-	-	-
N	FA	-	-	-	-	-	-	-	-	-	-	-	-
O	I	163	2.59	6	4.76	4	3.17	4	3.20	18	6.14	8	2.83
N	IL	165	2.63	-	-	2	1.59	2	1.60	6	2.05	5	1.77
-	LE	47	.75	2	1.59	1	.79	1	.80	1	.34	-	-
W	LP	-	-	-	-	-	-	-	-	-	-	-	-
O	LT	576	9.17	4	3.17	13	10.32	10	8.00	22	7.51	26	9.19
R	PT	327	5.21	1	.79	6	4.76	7	5.60	13	4.44	16	5.65
K	SP	-	-	-	-	-	-	-	-	-	-	-	-
	U	133	2.12	4	3.17	2	1.59	3	2.40	-	2.39	5	1.77
TOTALS		1411	22.46	17	13.49	28	22.22	27	21.60	67	22.87	56	19.79
GRAND TOTALS		6282	100.0	126	100.0	126	100.0	125	100.0	293	100.0	283	100.0

Table 9. Summary of Results, All Workers

	ELEMENTS	METHODS											
		C_1		C_2		M_1		M_2		M_4		M_5	
		f	%	f	%	f	%	f	%	f	%	f	%
	A	29401	37.21	537	34.03	589	37.32	598	37.94	1284	35.80	1345	37.71
	B	5399	6.83	95	6.02	109	6.91	107	6.79	286	7.97	222	6.23
	C	1223	1.55	13	.82	23	1.46	27	1.71	53	1.48	42	1.18
	CU	727	.92	15	.95	16	1.01	15	.95	37	1.03	31	.87
W	D	5258	6.65	125	7.92	106	6.72	110	6.97	228	6.36	210	5.89
O	LJ	7299	9.24	133	8.43	146	9.25	146	9.26	303	8.45	366	10.26
R	OP	2426	3.07	48	3.04	46	2.92	43	2.73	97	2.70	102	2.86
K	P	2164	2.74	42	2.66	40	2.53	41	2.60	104	2.90	110	3.08
	R	2079	2.63	48	3.04	41	2.60	40	2.54	87	2.43	103	2.89
	SU	1522	1.93	27	1.71	30	1.90	31	1.97	66	1.84	78	2.19
	T	2214	2.80	49	3.11	44	2.79	43	2.73	97	2.68	82	2.30
	W	3993	5.05	89	5.64	80	5.07	82	5.20	181	5.05	181	5.08
TOTALS		63705	80.62	1221	77.38	1270	80.48	1283	81.41	2822	78.69	2872	80.54
	CR	86	.11	3	.19	3	.19	1	.06	3	.08	2	.06
N	FA	527	.67	18	1.14	11	.70	10	.63	22	.61	14	.39
O	I	2337	2.96	93	5.89	52	3.30	40	2.54	126	3.52	109	3.06
N	IL	1631	2.06	23	1.46	34	2.15	29	1.84	61	1.70	90	2.52
-	LE	103	.13	7	.44	2	.13	2	.13	8	.22	3	.08
W	LP	240	.30	9	.57	5	.32	5	.32	11	.31	15	.42
O	LT	3929	4.97	84	5.34	25	4.74	74	4.70	191	5.33	180	5.05
R	PT	4894	6.19	85	5.38	98	6.21	99	6.28	282	7.86	219	6.14
K	SP	1429	1.81	31	1.96	26	1.65	30	1.90	53	1.48	57	1.60
	U	133	.17	4	.25	2	.13	3	.19	7	.20	5	.14
TOTALS		14309	19.38	357	22.62	308	19.52	293	18.59	764	21.31	694	19.46
GRAND TOTALS		79014	100.0	1578	100.0	1578	100.0	1576	100.0	3586	100.0	3566	100.0

0.04 x 11075, or 443.00 minutes, an experimental error of less than 0.23 per cent.

First Systematic Sample--M_1.--Starting with Frame No. 50, every 50th frame was examined for the activities being performed by the eight operators in the study. These were recorded using the mnemonic symbols as listed in Chapter II. When this systematic sample was completed, the results were summed in terms of the number of frames per occurrence per activity per man. These samples were coded as M_1 and are listed in Table 1 through Table 8 for each operator. They are also summed in Table 9 for all operators under this code symbol.

Second Systematic Sample--M_2.--Starting with Frame No. 25, every 50th frame was examined for the activities being performed by the eight operators in the study. These were recorded using the mnemonic symbols as listed in Chapter II. When this systematic sample was completed, the results were summed in terms of the number of frames per occurrence per activity per man. These samples were coded as M_2 and are listed in Table 1 through Table 8 for each operator. They are also summed in Table 9 for all operators under this code symbol.

First Random Sample--M_4.--From the book A Million Random Digits (39) two random numbers composed of three digits each were drawn. These numbers were 113 and 109. Using these numbers as page numbers, pages 113 and 109 were selected for the drawing of 500 random frame numbers. Page 113 was used for the first random film sample and page 109 for the second sample. Since the last frame number was 11448 and the random digits in this book were arranged in columns with each column containing five digits across, each five-digit number was selected to be a frame number. When a five-digit number had a numerical value greater than 11448, that number was reduced by multiples of 11448 to reduce that number to a value that was 11448 or less. For example, the first five-digit number was 38681. This number when reduced three times by 11448 becomes 04337. This number is then used to represent Frame No. 4337.

This procedure was repeated until 550 random frame numbers were obtained. The additional 50 frame numbers were selected to replace those frame numbers which would fall within the break periods and the lunch period.

The first 500 numbers selected were then arrayed in numerical sequence. The extra 50 numbers were not arrayed, but were left in the order of their selection. Those frame numbers that fell within the break periods and the lunch period were discarded and enough numbers were drawn from the extra 50 numbers, in the order of their appearance, until there were 500 random frame numbers, of which none occurred during any break or lunch period. The film was then sampled in the same fashion as the other studies. The results were likewise tabulated and are listed in the same tables under the code of M_4.

Second Random Sample--M_5.--The same procedure was used as with the first random sample, with the exception that page 109 was used instead of page 113. The results are also tabulated in the same tables under the code symbol M_5.

The 100% Film Sample--C_1.--After the above four samples, M_1, M_2, M_4, and M_5, were taken and tabulated, the entire film was analyzed frame by frame to obtain the true percentage distributions of each work and non-work element. The results are tabulated in the above tables and are coded as C_1.

The Sum of Samples M_1 and M_2--M_3.--Code M_3 is used for the sum of the samples taken in the first systematic sample (M_1) and in the second systematic sample (M_2).

The Sum of Samples M_4 and M_5--M_6.--Code M_6 is used for the sum of the samples taken in the first random sample (M_4) and in the second random sample (M_5).

The Statistical Analysis

The Variance Test.--When it is desired to compare the spreads or variabilities of two sets of figures, the F test (40) is used (Snedecor's variance ratio).

After the variances of each method are calculated, the ratio of the larger variance to the smaller is determined. This is termed the variance ratio of F. Attached to the variance ratio are two sets of degrees of freedom, n_1 for the larger variance, and n_2 for the smaller. (Set-up and sample calculations are shown in Appendix I).

When all of the variance ratios are calculated, the F table can be entered according to the two sets of degrees of freedom at any particular percentage level of significance.

For this problem, five variance ratios were computed: C_1/C_2; C_1/M_1; C_1/M_2; C_1/M_4; and C_1/M_5. The resultant values were 1.66, 1.53, 1.41, 1.74, and 1.64 respectively. Since each variance had eight samples, each variance ratio has seven degrees of freedom for each set: $n_1 = 7$, and $n_2 = 7$.

When the F tables with these two sets of degrees of freedom were entered, the significance level of 5 per cent was 3.9. If the value of the variance ratio is greater than that given in the variance table for the corresponding degrees of freedom, then the result is more significant than the significance level for the table.

All the calculated variances were less than the value required for significance at the 5 per cent level. Therefore, the hypothesis that the variabilities of the two methods are equal must be accepted for each of the computed ratios.

When these variances were tested for homogeneity using Cochran's Test (valid only when the sample variances have an equal number of degrees of freedom), the hypothesis of equal variances was accepted at the 95 per cent level of probability (7 d.f.) (41).

The methods could be unequal in variability because these results could be due to lack of sensitivity of this procedure, i.e., the change of variance as the function of the method employed might be masked by the basic variance (σ^2 of C_1), which is primarily attributable to the differences in men.

Consequently, it seems appropriate to use a non-parametric technique. In the classical techniques, such as the analysis of variance, a normal distribution is assumed. Since non-parametric techniques are concerned with comparisons between distributions and not between parameters, the need of specifying the type of distribution is obviated.

<u>The Ranking Technique</u>.--The non-parametric technique chosen for these data was the ranking technique, in which the experimental methods are ranked against the control or standard method.

By converting the frequencies of occurrences into percentages to facilitate comparisons, each work and non-work element of C_2, M_1, M_2, M_4, and M_5, in the following combinations, was ranked against the standard,

C_1, to determine which method most closely duplicated the standard. (See Appendix II for sample calculations.)

1. C_1 versus C_2, M_1, and M_4.
2. C_1 versus C_2, M_1, and M_5.
3. C_1 versus C_2, M_2, and M_4.
4. C_1 versus C_2, M_2, and M_5.
5. C_1 versus C_2, M_3, and M_6.

Under the hypothesis that all three methods should not differ from one another, in that the results from each method should be essentially the same, the χ^2 test was used to determine whether any one method differed significantly from the other.

Each of the above five combinations was tested for significance at the 95 per cent level using two degrees of freedom to enter the tables. In every case, strong significance was indicated and the hypothesis for each of the five cases was rejected.

When the frequencies of occurrences were set in tabular form (see Appendix III), the results indicated that the M_1, M_2, M_3 series approached the standard, C_1, most frequently, that the M_4, M_5, M_6 series was the next most frequent, and C_2 the least frequent.

Visual inspection of these results gave rise to the conjecture that the results apparently appeared in a 1:8:5 ratio, that is, in each of the above combinations (using Combination No. 1 to illustrate this point), M_1 occurred eight times more frequently than C_2, and M_4 occurred five times more frequently than C_2.

Using the χ^2 statistic to test the goodness of fit of the actual frequencies to this apparent ratio of occurrence, the hypothesis that the actual frequencies did appear in the ratio of 1:8:5 was accepted at the 95 per cent probability level (2 d.f.) for all combinations.

Since this was a "visual inspection" ratio, and since the ranking was replicated five times, the results of the five replications were summed, and the sum of that method which occurred the least frequently was used to divide all the sums of these replications to determine a ratio with unity as the base. This ratio was 1:6.577:4.196. This ratio means that the M_1, M_2, M_3 series was closer to the standard 6.577 times as often as C_2, and that the M_4, M_5, M_6 series was closer 4.196 times as often as C_2.

As a test of the validity of this ratio, the same procedure as outlined above was followed using the χ^2 statistic for goodness of fit on all five combinations.

The hypothesis that the results of the ranking technique do appear in the ratio of 1:6.577:4.196 was accepted at the 95 per cent probability level (2 d.f.) for all combinations.

The Chi Square Test (Contingency Tables).--Although it was now determined which method most closely approaches the standard, a quantitative result has not yet been obtained. To obtain a quantitative result, one type of enumeration statistics which uses two-way classification tables (frequently called contingency tables), can be used. For this analysis, a 2 x n contingency table where n is the number of methods considered was used. Since there were five methods under consideration as compared to the standard method, a 2 x 6 contingency table resulted. The χ^2 test for this 2 x 6 contingency table is similar to the F test with continuous data: it tests the null hypothesis that there are no differences in the true proportions of the non-work elements under the different methods.

A more expeditious method of calculating χ^2 was developed by Brandt and Snedecor (42). This method defines the statistic χ^2 as follows:

$$\chi^2 = \frac{\Sigma\, a_i p_i - \bar{p}\, \Sigma(a_i)}{\bar{p}\, \bar{q}} ,$$

where a_i = the number of non-work elements under the i^{th} method,

$\bar{p}$ = the average of the total number of non-work elements, and

$\bar{q}$ = $(1 - \bar{p})$.

For these data (see Appendix IV), the calculated χ^2 equals 23.66 (5 d.f.). This is significant at the 95 per cent probability level.

The next step was then to compare the individual methods. This was done by breaking down the contingency table into smaller tables. Since this distribution is discontinuous, whereas χ^2 is a continuous variable, and since contingency tables containing but one degree of freedom were used, the approximation of the χ^2 distribution can be markedly improved by reducing the absolute value of each difference by 0.5 before it is squared. This procedure is termed the "Correction for Continuity" (43).

For 2 x 2 tables, this correction can be included and the χ^2 statistic reduced to the following formula:

$$\chi^2 = \frac{(|ad - bc| - 1/2\ N)^2\ N}{(a + b)(a + c)(b + c)(c + d)} \qquad (44)$$

For these data, the results are listed in Table 10. (Set-up and sample calculations are in Appendix V.) All acceptances and rejections were made with one degree of freedom at the 95 per cent level of probability. An inspection of these results reveals the following relationships:

1. The systematic samples from the film compared favorably with the 100 per cent film sample.

2. The random samples from the film did not compare favorably with the 100 per cent film sample.

3. The concurrent systematic interval sample did not compare favorable with either the 100 per cent film sample, the systematic film samples, or the random film samples.

4. These results corroborated those obtained from the ranking technique.

Table 10. χ^2 Results from the 2x6 Contingency Table and the 2x2 Contingency Tables

The 2x6 Contingency Table

$\chi^2 = 23.66$ $\chi^2_{.95} = 11.07$ (5 d.f.) Hypothesis Rejected

The 2x2 Contingency Tables

Comparison	Calculated χ^2	Tabular χ^2	d.f.	Results of Hypothesis
C_1 vs. M_1	2.76	3.84	1	Accepted
C_1 vs. M_2	0.56	3.84	1	Accepted
C_1 vs. M_4	8.03	3.84	1	Rejected
C_1 vs. M_5	3.55	3.84	1	Accepted
C_2 vs. C_1	10.20	3.84	1	Rejected
C_2 vs. M_1	4.44	3.84	1	Rejected
C_2 vs. M_2	7.68	3.84	1	Rejected
C_2 vs. M_4	1.13	3.84	1	Accepted
C_2 vs. M_5	6.51	3.84	1	Rejected
M_1 vs. M_2	0.26	3.84	1	Accepted
M_1 vs. M_4	2.33	3.84	1	Accepted
M_1 vs. M_5	0.01	3.84	1	Accepted
M_2 vs. M_4	4.84	3.84	1	Rejected
M_2 vs. M_5	0.75	3.84	1	Accepted
M_4 vs. M_5	3.54	3.84	1	Accepted

CHAPTER IV

CONCLUSIONS

The purpose of this thesis is to determine whether the non-work activities developed from a memomotion film will yield results comparable to those developed from a concurrent systematic interval study, from a systematic sampling of the film, and from a random sampling of the film.

As a result of the statistical analysis of the data of the study, the following conclusions may be listed:

1. The variabilities of percentages between the operators were not significant.

2. The sampling methods varied significantly.

3. The systematic sampling of the film duplicated the true percentage distribution of the standard more closely than did the other two methods.

4. The systematic sampling of the film every two minutes adequately defined the non-work occurrences.

5. The random sampling of the film did not compare as well with the true percentage distribution of the standard as did the systematic sampling method. (See paragraph 1 below.)

6. The manual systematic interval study was the least accurate of all the methods under consideration.

7. The quantitative results from the χ^2 test of the contingency tables corroborated the results derived from the ranking technique.

To these conclusions, the following can be added:

1. It was extremely difficult to ascertain the activities of some of the workers in a single frame. A short sequence of frames is much easier to analyze since comparison between adjacent frames will determine the actual activity with greater accuracy. This method was used occasionally and may result in some bias due to the use of several frames instead of one. But, since this method was used in all four samples, it can be considered a constant.

2. When an operator moves outside the range of the camera, the reason for his absence was not readily ascertainable, unless he was seen re-entering the picture carrying parts and/or tools. Since the location of the tool cribs and part bins were known, as well as the location of the water fountain and the rest rooms, that activity which caused the operator to leave the picture could be assumed by the direction of his departure and re-entry. Personal trips to the water fountain could be seen since the fountain was visible in the extreme upper left hand corner of the film.

3. The use of a wide angle lens could provide additional information by providing coverage over a wider area.

4. The mounting of the camera some 14 feet in the air was a decided advantage. Even though there were many individuals who gathered around from time to time during the course of the study to see what was going on, they did not appear in the film at any time. This height also provided a clear view of those working in the background.

5. The camera required very little attention during the course of the study. With the use of a 200-foot capacity magazine loading camera instead of the 100-foot capacity reel loading camera that was used, just

three visits (instead of five) per day would be required for camera attention when it is operating at a rate of 25 frames per minute: a set-up period in the morning, a reloading period at lunch, and a removal period at the end of the day.

6. Since the results of this experiment indicate that a systematic sampling of the memomotion film yields the best results, a memomotion film taken at this rate (one frame per two minutes) could yield the same results.

7. With regard to Conclusion No. 6, the film cost would be reduced to one-fiftieth of that for memomotion film taken at 25 frames per minute. With the use of a suitable timing device, a 200-foot roll of film would last for more than 32 eight-hour working periods.

8. Although the initial cost of this equipment (the memomotion camera and related accessories) is relatively high, Conclusion No. 7 would materially assist in justifying the cost. When a single engineer is used for 32 eight-hour working periods at the rate of $4.00 per hour, the $1000 that it costs for this engineer for this period would just about cover the cost of this equipment. The use of this equipment in other work would also assist in the justification.

9. Another interesting conclusion was drawn from the sampling of the entire film: at no time could the writer discern an operator being conscious of the camera.

10. From a practical viewpoint, the developed percentages of the non-work activities from each of the various methods under consideration were all within plus or minus 10 per cent of the percentage that was developed from the 100 per cent sample of the film for the non-work

activities, with the single exception of the systematic interval study that was performed concurrently with the film: it was within 15 per cent.

CHAPTER V

RECOMMENDATIONS

It seems apparent that the results of this study demonstrate the feasibility of determining non-work activities with a systematic sample of a memomotion film for certain types of studies within the limitations imposed by this experiment. These limitations are as follows: the work under consideration is not cyclical, the observation is limited to the range of the camera, and those limitations that are inherent in any kind of mechanical and/or electrical equipment.

Since the time interval was arbitrarily selected as two minutes and was also determined by the length of the interval of the manual systematic interval study, it is recommended that further research be undertaken to ascertain the optimum interval of the systematic sample of the film to adequately define the non-work activities, that an economic balance be sought between the interval rate and cost of film versus the cost of the engineer performing a comparable interval study, and that this study can be expanded and repeated so that the results can be tested more rigorously than was possible within the universe of this experiment.

It is further recommended that, since it was easier to determine the activities of an operator by viewing a sequence of frames, an experiment be set up to determine the number of frames that would be required to adequately define the activities being examined, that the exposure rate of these frames be determined. To successfully determine the results of such an experiment, a motion picture camera will have to be modified to take multiple frames at regular intervals. These multiple frames will be controlled by one timer and the shutter of the camera will be controlled by another timer. This is in contrast to a memomotion camera which takes a single frame at regular intervals.

APPENDIX

APPENDIX I

Sample Calculations - F Test

1. Variance Equation

$$s^2 = \frac{\sum_{i=1}^{N} (x_i - \overline{x})^2}{N - 1}$$

$$s^2_{C_1} = \frac{\left(3,542.7685 - \frac{23,076.6481}{8}\right)}{7}$$

$$= 151.19$$

Computed Variance Values of Each Method

$C_1 = 151.19$	$M_2 = 107.01$
$C_2 = 91.29$	$M_4 = 86.74$
$M_1 = 98.72$	$M_5 = 92.37$

2. Variance Ratio (F Test)

$$F = (s^2_1 / s^2_2$$

$$= 151.19/91.29$$

$$= 1.66 \qquad F_{.95} = 3.8 \text{ (7 d.f., 7 d.f.)}$$

Computed Variance Ratio Values

$C_1/C_2 = 1.66$	$C_1/M_4 = 1.74$
$C_1/M_1 = 1.53$	$C_1/M_5 = 1.64$
$C_1/M_2 = 1.41$	

APPENDIX II

Sample Calculations - Ranking Technique

1. Ranking

a. From Table 1, Worker A, Summary of Results, the per cent of occurrence of Element A, for each method, is as follows:

$C_1 = 33.71\%$	$M_2 = 32.58\%$
$C_2 = 32.58\%$	$M_4 = 33.20\%$
$M_1 = 33.94\%$	$M_5 = 31.20\%$

b. Using the first comparison, C_1 vs. C_2, M_1, and M_4, the absolute differences between the standard, C_1, and the experimental methods for Element A are determined:

1. $|C_1 - C_2| = |33.71 - 32.58| = 1.13$
2. $|C_1 - M_1| = |33.71 - 33.94| = 0.23$
3. $|C_1 - M_4| = |33.71 - 33.20| = 0.51$

c. The least difference is tabulated in a table, a section of which is reproduced below, using the coded symbol of that method:

C_1 versus C_2, M_1, M_4

Elements	Worker A	Worker B	Worker C	Worker D
A	M_1	(C_2)*	(M_1)*	(C_2)*
B	-	-	-	
C	(C_2)*	(M_4)*	-	
[illegible]	(M_4)*	(M_4)*	-	
D	(M_4)*			

()* These are the results of later computations. Parentheses have been used solely to indicate the positioning of M_1 in the table, the result of the sample calculations above.

APPENDIX II (Continued)

2. Summary of Results from Ranking

a. From the results tabulated in the preceding table, a summation of each element was made, in terms of methods, to ascertain the frequency of occurrence of each method. The following table lists the results of the five comparisons under consideration:

b.

$C_2 = 8.5$	$M_1 = 63.5$	$M_4 = 42.0$
$C_2 = 7.5$	$M_1 = 66.5$	$M_5 = 40.0$
$C_2 = 10.0$	$M_2 = 62.5$	$M_4 = 41.5$
$C_2 = 15.5$	$M_2 = 61.5$	$M_5 = 36.0$
$C_2 = 7.0$	$M_3 = 65.0$	$M_6 = 44.0$

c. Since two or more methods could have the same differences, both or all three were tabulated as C_c/M_y, M_x/M_y, or $C_x/M_y/M_2$. When the results were summed, the double or triple entry was given one-half or one-third weight, as the case may be.

APPENDIX III

Results of the Ranking Technique

							Totals	T.F.*
1.	C_2	8.5	M_1	63.5	M_4	42.0	114	38
2.	C_2	7.5	M_1	66.5	M_5	40.0	114	38
3.	C_2	10.0	M_2	62.5	M_4	41.5	114	38
4.	C_2	15.5	M_2	61.5	M_5	36.0	113	37-2/3
5.	C_2	7.0	M_3	65.0	M_6	44.0	117	38-2/3
Totals		48.5		319.0		203.5		

T.F.* Theoretical Frequency of Occurrence

Sample Calculations

Using Results of Combination No. 1 Above)

$$\chi^2 = \frac{(38 - 8.5)^2}{38} + \frac{(63.5 - 38)^2}{38} + \frac{(42 - 38)^2}{38}$$

$$= 40.43 \text{ (2 d.f.)}$$

$$\chi^2_{.95} = 5.99 \text{ (2 d.f.)}$$

APPENDIX IV

The 2x6 Contingency Table and Sample Calculation

		C_1	C_2	M_1	M_2	M_4	M_5	Totals	
(a_i)	Work	63705	1221	1270	1283	2822	2872	73173	$(\Sigma\ a_i)$
	Non-Work	15309	357	308	293	764	694	17725	
	Totals	79014	1578	1578	1576	3586	3566	90898	
(p_i)	% Non-Work	0.1938	0.2262	0.1952	0.1859	0.2131	0.1946	0.1950	$(\overline{p})$

$$\chi^2 = \frac{\Sigma a_i p_i - \overline{p}\ \Sigma (a_i)}{\overline{p}\ \overline{q}}$$

$$= \frac{3460.0887 - (0.1950)(17725)}{(0.1950)(1-0.1950)}$$

$$= 23.66 \text{ (5 d.f.)}$$

$$\chi^2_{.95} = 11.07 \text{ (5 d.f.)}$$

APPENDIX V

The 2x2 Contingency Table and Sample Calculation for the Correction of Continuity

	I	II	Totals
1	a	b	a+b
2	c	d	c+d
Totals	a+c	b+d	a+b+c+d = N

	C_1	M_2	Totals
Work	63795	1283	64988
Non-Work	15309	293	15602
Totals	79014	1576	80590

$$\chi^2 = \frac{(|ad - bc| - 1/2\ N)^2\ N}{(a+b)(a+c)(c+d)(c+d)}$$

$$= \frac{(|63705 \times 293 - 1283 \times 15309| - 1/2 \times 80590)^2\ 80590}{(64988)(79014)(1576)(15602)}$$

$$= .56$$

$$\chi^2_{.95} = 3.84 \text{ (1 d.f.)}$$

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